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The bakelite for the RPCs of the experiment CMS

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Abstract

Results from aging tests on the bakelite used for the CMS RPCs are presented. Samples of melaminic bakelite were exposed to a heavy gamma and neutron radiation. Data on the bulk resistivity were collected while accumulating gamma and neutron doses and particles fluence up to values well beyond those expected in 10 years of RPCs operation in the barrel region of CMS. The test with gamma radiation was performed at the CERN Gamma Irradiation Facility (GIF) with a 20 Ci ^{137}Cs source. A total absorbed dose of 5 Gy was accumulated during an irradiation period of about one month. The test with both neutron and gamma radiation was held at the Triga Mark II 250 kW reactor located in Pavia. A total of 80 h of exposure were accumulated integrating a neutron and gamma dose of about 80 Gy and a fast neutron fluence of some 10^{11} cm^{-2}. Experimental data on dose rate in both the test facilities have been compared to simulation output and show a good agreement.

Keywords: Resistive plate chambers; Bakelite; Neutron and gamma irradiation

CMS Resistive Plate Chambers (RPCs) are expected to work in a very hostile radiation environment mainly due to neutron and gamma radiation. In this view it is interesting to study the behavior of the RPCs composite materials, including front-end electronics. The following results are part of a general plan foreseen to test the aging of each of the main components of the detector while other tests are being doing to measure the whole RPCs sensitivity to neutron and gammas. One of the interesting issues concerning the bakelite is so related to its behaviour under irradiation. In particular, data on gammas and neutrons are often missed.

We report on the results of a test made at the CERN Gamma Irradiation Facility where a set of bakelite samples were exposed to a high ^{137}Cs gamma flux. The samples were put into a box just

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in front of the source. The usual RPCs gas mixture[1] supplied the box. The bakelite volume resistivity was monitored during time while the samples integrated a certain gamma dose. The external temperature was monitored to correct the resistivity reading. A detailed simulation [1,2] of the GIF area, of the source and of the lead-absorbing filters was used to calculate the dose rate absorbed by the bakelite, giving an average value of 0.6 rad/h.

A total of about 800 h of irradiation were accumulated and the results summarised in Fig. 1a and 1b where the volume resistivity of a phenolic (Fig. 1a) and a melaminic (Fig. 1b) sample is plotted as a function of the accumulated dose. The resistivity value ρ_T measured at the temperature T has been corrected to give the value of resistivity ρ_{20} at $T = 20^\circ$C using the function $\rho_{20} = \rho_T \times 0.99 \times e^{0.128(T-20)}$. The function is the result of an exponential fit to the data points shown in Fig. 2 where ρ_{20}/ρ_T for different bakelite samples is plotted as a function of the temperature. The comparison among the values of resistivity with source on and with source off shows a minimal variation of the volume resistivity up to at least 5 Gy and hence no damage during irradiation. A cumulative effect seems to appear at 5 Gy for the melaminic sample; however, the factor 2 variation with respect to the initial values is not significant compared to the running time of the experiment CMS equivalent to such a dose (about 50 years for the barrel region).

The CMS bakelite RPCs will be exposed also to neutrons, thus, an indication of the neutron induced aging is mandatory. Typical values for neutrons flux (cm^{-2} s^{-1}) in CMS will ranges from 20 to 600 in the barrel region and from 1000 to some 10 000 in the forward region. Similar figures are expected for photons. A test simulating such an environment over several years would require a neutrons and gammas fluence of at least 10^{10} cm^{-2}. Neutrons and gammas from reactors facilities are right adequate to this plan.

In the following we describe a test made at the Triga Mark II 250 kW nuclear reactor in Pavia where some bakelite samples have been irradiated. The thermalising column of the reactor allows exploiting a beam of neutrons whose energy extends up to 10 MeV. In a particular configuration, a boral window can be inserted at the end of the column to cut the thermal neutrons allowing to work with a discrete flux of fast neutrons.

Fig. 3 shows a simulation result which compares the neutron flux in the two configurations. The

[1] 97% $C_2H_2F_4$–3% iC_4H_{10}.

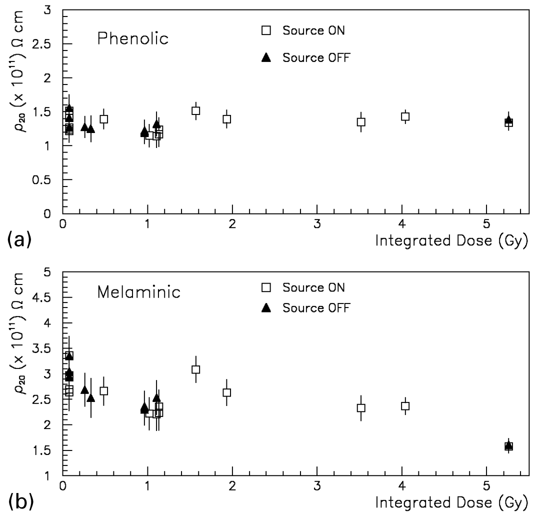

Fig. 1. Phenolic (a) and melaminic (b) bakelite volume resistivity at $T = 20^\circ$C vs. dose in the configurations: source ON, source OFF.

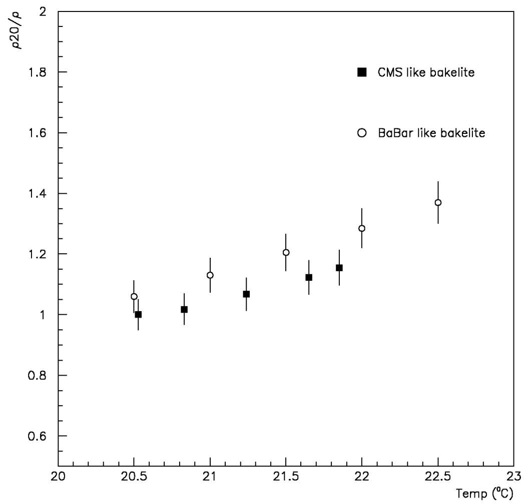

Fig. 2. Bakelite ρ_{20}/ρ_T vs. temperature for a CMS like bakelite (full squares) and for a Babar like bakelite (open circles).

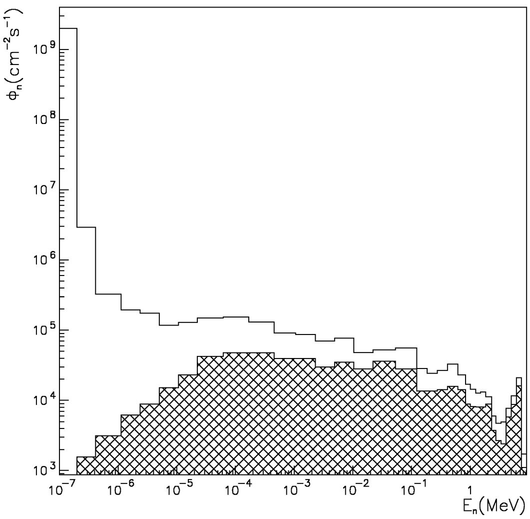

Fig. 3. Simulation of the neutron flux at the end of the thermalising column of the Triga Mark II reactor according to the configuration set: a boral window can be placed to cut the high contribution of the thermal neutrons. The resulting spectrum (shaded) is superimposed.

simulation has been done with a neutrons and gammas transport code [3] that took into account the reactor core geometry as well as the materials along the thermalising column.

Fig. 4a shows a comparison between the energy spectra $E\mathrm{d}\phi/\mathrm{d}E$ ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) expected from the reactor with the boral window inserted and at the first station (MB1) of the CMS muon barrel [4]. The ratio between the two fluxes is variable in the range 425–2100 according to the test position. On the other hand, in the usual configuration, i.e. without the boral window, it is possible to have a thermal neutron flux as high as $10^9\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$.

In terms of dose, however, much of the contribution comes from gammas which emerge from the neutron capture reactions taking place into the graphite along the beam path. Fig. 4b shows, on the same scale, the simulated gamma and neutron dose rate (D_γ, D_n) and the neutron flux (ϕ_n) as a function of the distance from the boral window. Moreover, two experimental data on gamma dose rate are evidenced. Four samples of bakelite $15 \times 15 \times 0.2\ \mathrm{cm}^3$ were located downstream the boral window at the end of the thermalising column of the reactor. The samples were placed

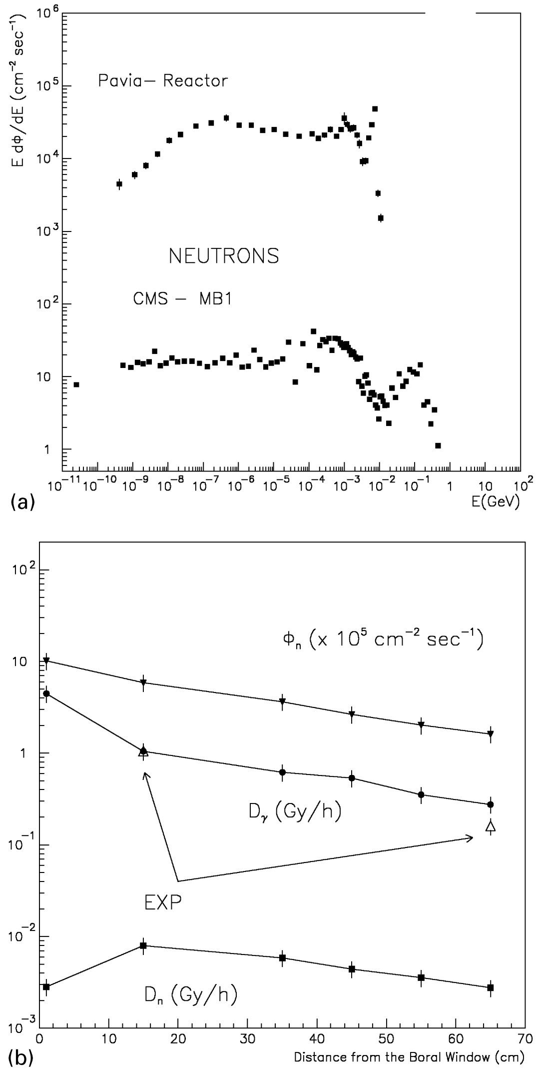

Fig. 4. (a) Simulation of the reactor yields $E\mathrm{d}\phi/\mathrm{d}E$ ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) compared to what is expected in the first station (MB1) of the CMS muon barrel (boral window inserted); (b) Simulated gamma (full circles) and neutron (full squares) dose rate as a function of the distance from the boral window. Direct measurements on gamma dose rate at 15 and 65 cm are evidenced (open triangles). The fast neutron flux ($\times 10^5\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) as a function of the distance is also shown (full triangles).

at 15 cm from the boral window where a total fast neutron ($0.4\ \mathrm{eV} < E_\mathrm{n} < 10\ \mathrm{MeV}$) fluence of $1.6 \times 10^{11}\ \mathrm{cm}^{-2}$ and a total dose of 80 Gy was accumulated in 75 h over three irradiation periods from July to October 1999.

Additional 5 h of irradiation were accumulated with the boral window opened so as to have a main thermal ($E_n < 0.4$ eV) neutrons fluence of 3.4×10^{12} cm^{-2}. For our bakelite samples the ratio of the absorbed dose from gammas and from neutrons was about 100 while the ratio of the fluxes was about 280. The bakelite volume resistivity was monitored during the irradiation, as well as the temperature T and the humidity H inside the test location.

The bakelite resistivity was measured through the voltage drop V_{drop} on a sensing resistor (10^6 Ω) in series with the bakelite to which 500 V were applied by means of graphite 5 cm diameter electrodes. Taking into account the electrodes geometry the bakelite resistivity could then be obtained by $\rho = 5 \times 10^{10}/V_{drop}$ (Ω cm).

Moreover, since $\Delta V_{drop}/V_{drop} = \Delta\rho/\rho$, in the following plots we will refer to the resistivity in term of voltage. During the test we experienced a large variation of the humidity with a corresponding variation of the resistivity reading. Fig. 5 shows an example of this correlation over a certain period of time outside the reactor.

It is interesting to note that whenever the humidity rises the resistivity reading drops; the opposite is obviously true for the V_{drop} reading, i.e. V_{drop} strictly follows the humidity curve. Moreover, the V_{drop} curve can be very well approximate (far from the irradiation periods) by rescaling the humidity curve. This is well shown in Fig. 6 where the humidity (full squares) and V_{drop} (full triangles) are plotted as a function of the time. The points between the lines indicate irradiation periods of 3 and 8 h, respectively. The rise of the humidity inside the reactor thermal column has been noted right after the beginning of each irradiation period. To isolate the contribution due to the neutrons we used the humidity curve before each irradiation period as a point-to-point normalisation factor for V_{drop}. The open circles of Fig. 6 are thus obtained by rescaling the humidity curve inside each irradiation period with the average ratio V_{drop}/H as calculated outside the irradiation periods. The difference between full triangles and open circles would then be the neutron irradiation contribution.

It can be noted how during few hours of irradiation there is not a sensible variation of the

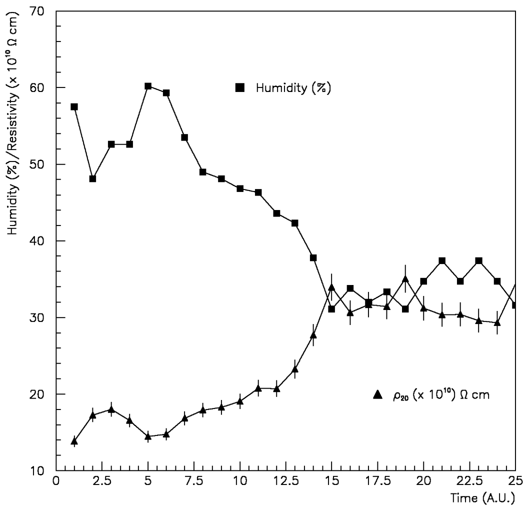

Fig. 5. Correlation between humidity (full squares) and bakelite resistivity reading (full triangles). The resistivity is normalised at $T = 20°$C.

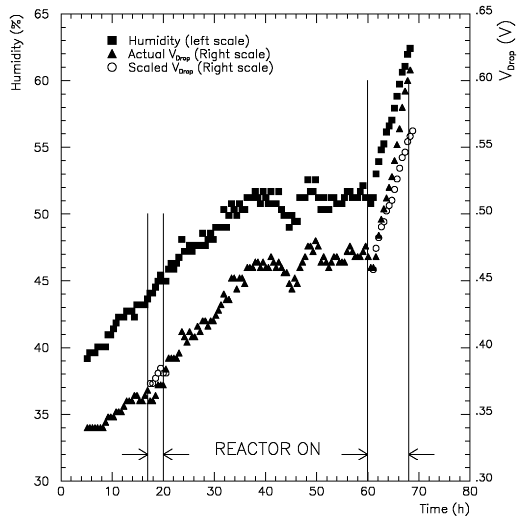

Fig. 6. Example of humidity (left scale, full squares) and V_{drop} (right scale, full triangles and open circles) as a function of the time during the last period of irradiation at the Pavia Reactor. The bakelite resistivity can be obtained through the formula $\rho = 5 \times 10^{10}/V_{drop}$ (Ω cm) as explained in the text. The lines define two irradiation periods of 3 and 8 h, respectively. Outside the lines, the voltage curve (full triangles) can be very well approximate by rescaling the humidity and this was used to disentangle the neutron contribution during irradiation as described in the text. The temperature inside the test location was 22°.

resistivity while during a long irradiation period lasted 8 h we estimated a variation of the resistivity $\Delta\rho/\rho = \Delta V_{\text{drop}}/V_{\text{drop}} \simeq 10\%$. We remind that during 8 h of irradiation we accumulated a fast neutron fluence of 1.7×10^{10} cm^{-2} and a gamma fluence of 4.8×10^{12} cm^{-2}, the total absorbed dose (due to neutrons and gammas) being 8 Gy. By measuring the resistivity at the very beginning of the test and after 49 h of irradiation the percentage variation $\Delta\rho/\rho$ was measured to be only 18%. This suggest for the bakelite a sort of recovering behavior after each irradiation.

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